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A NOMOGRAPH FOR THE SOLUTION OF TOWCABLE CHARACTERISTICS FOR ST--ETC(U)
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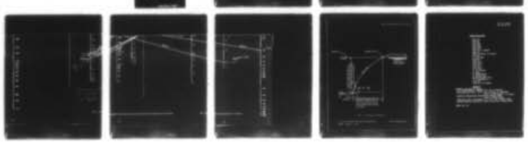

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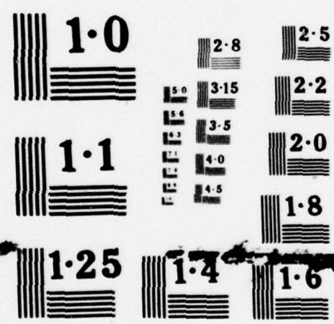
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(6)

A NOMOGRAPH FOR THE SOLUTION OF TOWCABLE CHARACTERISTICS FOR STEADY-STATE TOWED BODIES

By

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and
Matthew F. Borg

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(11) 1 April 1963

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INTRODUCTION

For the design of a VDS system that employs a towcable and a towed body, it is necessary to predict the maximum towcable tension and the trail and depth of the towed body. This memorandum discusses the design and use of a nomograph that was developed so that the relationships among cable functions and towcable tensions, towcable lengths, and the horizontal and vertical projected distances between the towed body and some other point of interest may be more readily available. The trail and depth of the towed body can also be found. In applying the nomograph, only arithmetical operations are used.

BACKGROUND

A check between measured and theoretical towcable characteristics is valuable. This check cannot easily be made if a large number of calculations must be performed.

The integral expressions for towcable geometry and forces that are derived in reference (a) include four non-dimensional cable functions, τ, ξ, η, and σ. (For definitions and symbols see Glossary of Terms.) The cable functions for any one towcable depend upon the angle ϕ at any point along the towcable and two ratios of cable parameters. One ratio, f, expresses the relative resistance of the cable (i.e., ratio of the tangential to the normal cable drag coefficients), and the other ratio, w, expresses the critical angle of tow for the towcable.

Reference (b) was written to simplify the use of the cable functions contained in the tables of reference (a); the tabular functions of reference (a) are graphed with an accuracy of four per cent; numerical examples are also given.

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The present memorandum should further aid the user of references (a) or (c), since it provides a nomograph that will permit swifter computations to be made.

DESIGN OF THE NOMOGRAPH

To design the nomograph, the following information is needed:

a. the equations relating the variables;

b. the range of the variables;

c. the determination of the dependent variables;

d. the identification of the type of equation; and,

e. the scale modulus or unit of representation to be used in making the desired variable scales fit on the sheet of paper.

Information for the design of the nomograph was obtained from reference (d).

a. Equations Relating the Variables

Four basic equations are involved in the nomograph design. The equations relate the non-dimensional cable functions $\tau, \sigma, \xi,$ and η to the towcable tension, length, horizontal projection of length, and vertical projection of length, respectively. These equations are from reference (a):

Towcable Tension

τ

$$T = T_o \frac{\tau}{\tau_o} \qquad (1)$$

N-D Cable f'n Associated with Tension — Dep V. T

Towcable Length

σ

$$S = \frac{T_o(\sigma - \sigma_o)}{R\tau_o} \qquad (2)$$

N-D Cable f'n Assoc w/ Length — cable drag (nominal) — Dep V R

Towcable Horizontal Projection

ξ

$$X = \frac{T_o(\xi - \xi_o)}{R\tau_o} \qquad (3)$$

N-D Cable f'n Assoc. with x — Dep V R

Towcable Vertical Projection

η

$$Y = \frac{T_o(\eta - \eta_o)}{R\tau_o} \qquad (4)$$

Dep V. R

See Glossary of Terms for the definitions and symbols used.

b. Range of the Variables

From references (a) and (c) and discussions with members of the Laboratory, the following ranges were established as those that are representative in the design of a Variable Depth Sonar system.

Towcable tensions (pounds):	$10 \leq T \leq 1{,}000{,}000$
Towcable lengths (feet):	$1 \leq S \leq 1{,}000$
Cable Friction (pounds/foot):	$0.1 \leq R \leq 1{,}000$
Tension Cable Function:	$1 \leq \tau \leq 10$
Length Cable Functions:	$0 \leq (\sigma - \sigma_o) \leq 10$
Horizontal Projection Cable Functions:	$0 \leq (\xi - \xi_o) \leq 10$
Vertical Projection Cable Functions:	$0 \leq (\eta - \eta_o) \leq 10$
Trail Distances (feet):	$1 \leq X \leq 1{,}000$
Depth Distances (feet):	$1 \leq Y \leq 1{,}000$

c. Determination of the Dependent Variables

From equations (1) through (4), it is seen that two terms, τ and T_o, appear in each equation and that the cable resistance, R appears in three equations. The other variables in each equation are the cable function itself, τ, in equation (1), or the difference between the function at an arbitrary point of interest and at the towpoint, e.g., $(\sigma - \sigma_o)$; $(\xi - \xi_o)$; and $(\eta - \eta_o)$.

In order to determine which of the above variables should be the dependent variable, the test product is calculated, (see reference (d)). The test product is defined as the ". . . product of the coefficient of a variable in its plotting equation and of the extent of its assigned range. . ." Utilizing equations (1) through (4), the ranges established above and the test product, it has been determined that for equation (1), the dependent variable is T, and for equations (2), (3), and (4), the dependent variable is R.

d. Identification of the Type of Equation

With the two dependent variables, T and R, equations (1) through (4) are next written in terms of the dependent variables. In addition, the equations are written in logarithmic form, in order to construct the nomograph. Rewriting equations (1) through (4):

log form
1 thru 4
Dep V.

$$\log T = \log T_o + \log \tau - \log \tau_o \tag{1A}$$

$$\log R = \log T_o + \log (\sigma - \sigma_o) - \log \tau_o - \log S \tag{2A}$$

$$\log R = \log T_o + \log (\xi - \xi_o) - \log \tau_o - \log X \tag{3A}$$

$$\log R = \log T_o + \log (\eta - \eta_o) - \log \tau_o - \log Y \tag{4A}$$

Equations (1A) through (4A) are of a form referred to as "Equations with Four or More Variables," (see reference (d)). These types of equations have significance for nomographic plotting in indicating how auxiliary non-graduated scales should be constructed.

The auxiliary scales are obtained as follows:

Let $\log T_o - \log \tau_o = Q.$

Inserting the above expression into equations (1A) through (4A), one obtains:

$$\log T = \log \tau + Q \tag{1B}$$

$$\log R = \log (\sigma - \sigma_o) - \log S + Q \tag{2B}$$

$$\log R = \log (\xi - \xi_o) - \log X + Q \tag{3B}$$

$$\log R = \log (\eta - \eta_o) - \log Y + Q \tag{4B}$$

Letting:

$$P_1 = Q - \log S$$

$$P_2 = Q - \log X$$

$$P_3 = Q - \log Y$$

Equations (1B) through (4B) are written as:

$$\log T = \log \tau + Q \tag{5}$$

$$\log R = \log (\sigma - \sigma_o) + P_1 \tag{6}$$

$$\log R = \log (\xi - \xi_o) + P_2 \tag{7}$$

$$\log R = \log (\eta - \eta_o) + P_3 \tag{8}$$

Equations (5) through (8) have been calibrated in Figure (1), the nomograph. Q and P are the uncalibrated auxiliary scales.

e. Scale Modulus or Unit of Representation

The scale modulus, M, is a "mapping factor" which fits the range of the variables on the sheet of paper containing the nomograph and establishes the separation distance between the vertical scales. The equation used to determine the scale modulus is, from reference (d):

$$\text{Paper distance} = M \left[(\text{upper range of variable}) - (\text{lower range of variable}) \right]$$

This distance has been utilized in making the nomograph.

USE OF THE NOMOGRAPH

Figure 1 is a plot of equations (1) through (4), in nomograph form. Equations (5) through (8), derived from equations (1) through (4), were used in making the nomograph. The pertinent symbols are defined both in the Glossary and in Figure 1. An example of the use of the nomograph is also shown and explained on Figure 1. Figure 2 shows the geometry of a towed system.

Prior Information Needed Before Using Nomograph

The nomograph, Figure 1, will give the tension in, and the configuration for, the towcable. However, some other computations must be performed in order to obtain the non-dimensional cable functions that are needed, so that Figure 1 may be utilized. Reference (c) lists the information that is needed and illustrates the procedures that should be followed to obtain this information. It is suggested that both reference (c) and the present memorandum be used conjointly in solving towing problems.

Example

For a VDS towing operation, assume that the following information has been obtained by means of the procedures shown in reference (c):

1. Speed of tow = 20 knots;
2. Water weight of towed body = L_o = 5562 pounds;
3. Horizontal drag force against towed body = D_o = 1245 pounds;
4. Water weight of towline = W = 2.74 pounds/foot;
5. Cable drag of towline normal to stream = R = 20 pounds/foot;
6. Resultant tension at towstaff of towed body = T_o = 5700 pounds;
7. Towstaff angle, $\tan^{-1} \frac{L_o}{D_o} = \phi = 77° - 25'$;
8. Critical Angle of tow for towline = $\phi \approx 20°$; and
9. Length of cable payed out = S = 500 feet.

With the above information, it is found from reference (c) that the non-dimensional cable functions at the towstaff point, are:

$$\tau_o = 1.034$$

$$\sigma_o = 0.238$$

$$\xi_o = 0.027$$

$$\eta_o = 0.236$$

The subscript zero refers to the towstaff point.

Solution

(See Figure 1)

Step 1. Lay a straightedge from the T_o scale at 5700 pounds to the τ_o scale at 1.034.

Step 2. Mark the point of intersection of the straightedge with the non-graduated "Q" scale.

Step 3. Lay a straightedge from the point on the "Q" scale, step 2, to the "R" scale at 20 pounds/foot.

Step 4. Mark the point of intersection of the straightedge with the non-graduated "P" scale.

Step 5. Lay a straightedge from the S scale at 500 feet and the point of intersection on the "P" scale, step 4.

Step 6. Mark the point of intersection on the $\Delta\sigma$ scale. The value of $\Delta\sigma = (\sigma - \sigma_o) = 1.75$

Since $\sigma = 0.238$, the value of σ at the surface of the water is obtained as follows:

$$\Delta\sigma = (\sigma - \sigma_o) = 1.75 = \sigma - 0.238,$$

or $\sigma = 1.9888$.

Referring again to reference (c), it is found that for $\phi_c = 20^o$ and $\sigma = 1.988$, the surface towangle, ϕ, is approximately 33^o. Using $\phi_c = 20^o$ and $\phi = 33^o$, from reference (c), the remaining functions are found to be:

$$\tau = 1.24$$
$$\xi = 1.19$$
$$\eta = 1.55$$

Therefore,

$$\Delta\xi = \xi - \xi_o = 1.19 - 0.027 = 1.16$$
$$\Delta\eta = \eta - \eta_o = 1.55 - 0.236 = 1.31$$

Step 7. Lay a straightedge from the τ scale at 1.24, to the point of intersection on the "Q" scale, Step 2.

Step 8. Mark the point of intersection with the T scale, 6900 pounds. This represents the tension in the cable at the surface of the water.

Step 9. Lay a straightedge from the $\Delta\xi$ scale at 1.16, to the point of intersection on the "P" scale, Step 4.

Step 10. Mark the point of intersection with the X scale, 325 feet. This represents the trail distance of the towed body.

Step 11. Lay a straightedge from the $\Delta\eta$ scale at 1.31, to the point of intersection on the "P" scale, Step 4.

Step 12. Mark the point of intersection with the Y scale, 365 feet. This represents the depth of the towed body.

Summary of Calculations

At a towing speed of 20 knots, with a cable-payed-out length of 500 feet and a towstaff tension of 5700 pounds, the towcable tension at the surface is 6900 pounds, the trail distance of the towed body is 325 feet, and the depth of the towed body is 365 feet.

CONCLUSION

A nomograph has been prepared that provides simple solutions of towed-body VDS problems. Provided that preliminary information on the characteristics of the towed body and towline are known, the nomograph facilitates computations of (1) towline tension at any particular point along the cable, and (2) the horizontal or vertical projected distances from the towed body to the point of interest. The towed body trail and depth can also be determined.

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Student Trainee

Matthew F. Borg
MATTHEW F. BORG
Mechanical Engineer

GLOSSARY OF TERMS

Symbol	Definition	Units
D_o or F_D	Horizontal Drag Force against towed body	lbs.
L_o	Water Weight of towed body	lbs.
M	Scale Modulus	in./unit dimension
P	Uncalibrated Scale	-
Q	Uncalibrated Scale	-
R	Cable Drag when cable is normal to direction of motion	lbs./ft.
S	Length of Cable from towed body attachment point to any point on the cable	ft.
T	Tension at any point on the cable	lbs.
T_o	Tension at towpoint (at towstaff)	lbs.
w	Non-dimensional ratio W/R	-
W	Waterweight of towline per unit length	lbs./ft.
X	Horizontal projected distance from towpoint to point of interest (trail when surface point is used, See Fig. 2)	ft.
Y	Vertical projected distance from towpoint to point of interest (depth when surface point is used, see Fig. 2)	ft.
η	Non-dimensional cable function associated with Y distance	-
$\Delta\eta$	$\eta - \eta_o$	-
ξ	Non-dimensional cable function associated with X distance	-
$\Delta\xi$	$\xi - \xi_o$	-
σ	Non-dimensional cable function associated with S length	-
$\Delta\sigma$	$\sigma - \sigma_o$	-
τ	Non-dimensional cable function associated with T tension	-
$\Delta\tau$	$\tau - \tau_o$	-
ϕ	Angle between tangent to the cable and the direction of motion at any point on the cable	degrees
ϕ_c	Value of ϕ when cable (by itself) is towed freely ($\phi_c = f(W/R)$)	degrees

Subscript zero refers to towstaff point.

List of References

(a) Pode, L.,"Tables for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream," DTMB Report No. 689, March 1951

(b) Whicker, L. F., "The Oscillatory Motion of Cable-Towed Bodies," Ph.D. Dissertation, University of California, 16 July 1957

(c) Borg, M.F., "Towed Body Solutions Using Graphs of the Non-Dimensional Cable Functions," USL Technical Memorandum No. 933-27-63 of 1 April 1963 (UNCLASSIFIED)

(d) Johnson, L.H., "Nomography and Empirical Equations," John Wiley & Sons, Inc., New York, 1952.

(e) DelSanto, R. F., Jr., "Variable Depth Sonar - A Summary Report to 1962," USL Report No. 532, 4 January 1962 (CONFIDENTIAL)

Nomeature

P, Q = Uncalibrated scales

T_o = Resultant tension at towstaff point

R = Drag per unit length of cable when normal to the stream

s = Distance along the cable measured from the towstaff to any chosen point

x = Horizontal projection of cable length, s (Also called trail of towed body)

y = Vertical projection of cable length, s (Also called depth of towed body)

T = Towline tension at any chosen point between the towstaff and surface

τ = Non-dimensional cable function for towline tension

σ = Non-dimensional cable function for towline length, s

ξ = Non-dimensional cable function for towline distance, x

η = Non-dimensional cable function for towline distance, y

$\Delta\sigma = \sigma - \sigma_o$

$\Delta\xi = \xi - \xi_o$

$\Delta\eta = \eta - \eta_o$

Subscript zero refers to towstaff point

Example (s

Known: a. Water we
b. Horizont
c. Resultant
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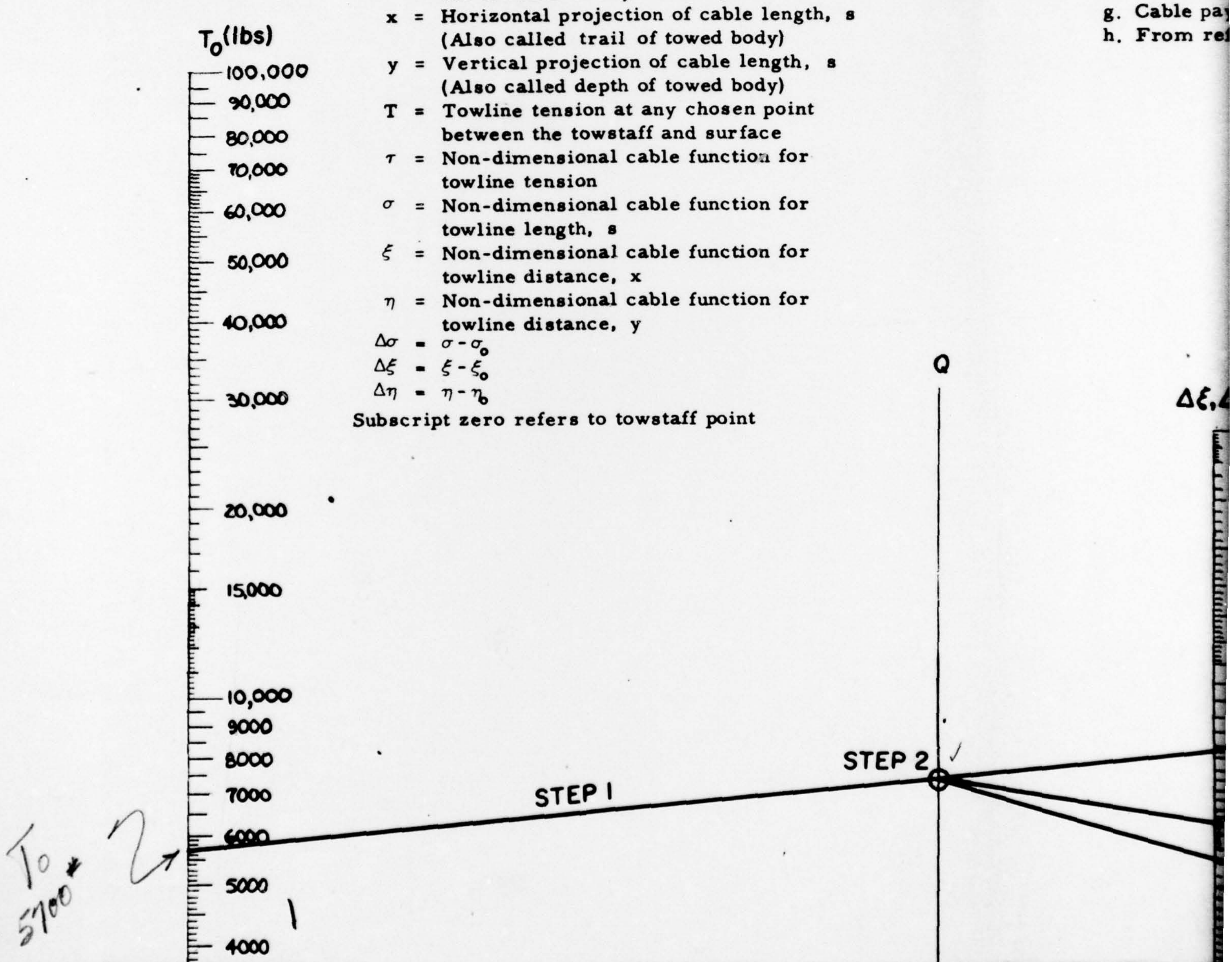

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ght of towed body = L_o = 5562 pounds
l drag force against towed body = D_o = 1245 pounds
tension at towstaff = T_o = 5700 pounds
angle = ϕ_o = 77°-25'
mal to the towline = R = 20 pounds/foot
ngle of tow for towline = $\phi_c \approx$ 20°
ed out = s = 500 feet
erence (c), τ_o = 1.034
σ_o = 0.238
ξ_o = 0.027
η_o = 0.236

Steps in using the nomograph

Step 1. Lay a straightedge from the T_o scale at 5700 pounds to the τ_o scale at 1.034

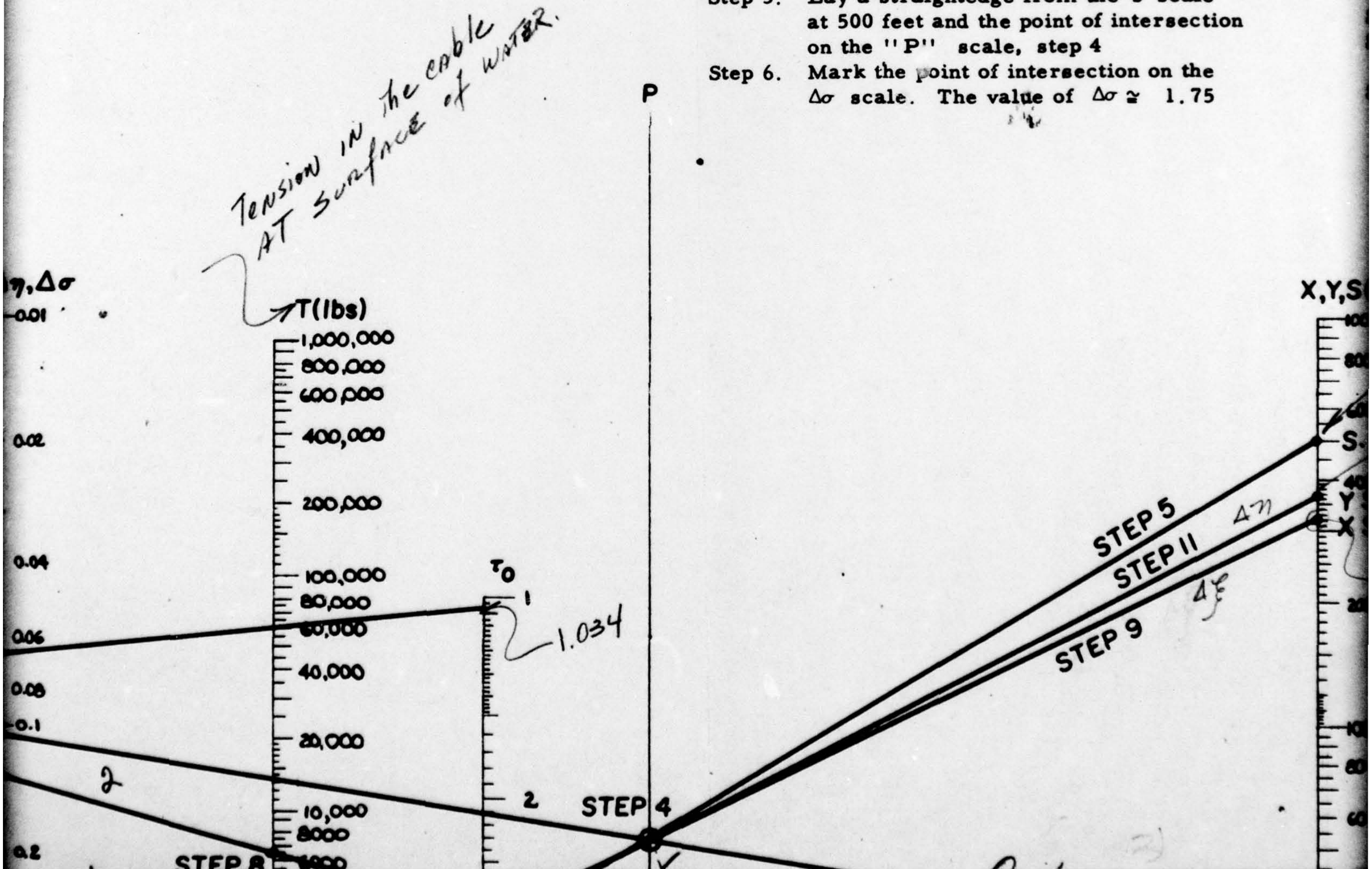
Step 2. Mark the point of intersection of the straightedge with the nongraduated "Q" scale

Step 3. Lay a straightedge from the point on the "Q" scale, step 2, to the R scale at 20 pounds/foot

Step 4. Mark the point of intersection of the straightedge with the nongraduated "P" scale

Step 5. Lay a straightedge from the s scale at 500 feet and the point of intersection on the "P" scale, step 4

Step 6. Mark the point of intersection on the $\Delta\sigma$ scale. The value of $\Delta\sigma \cong$ 1.75



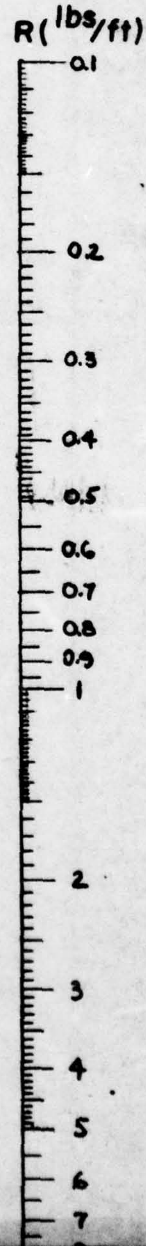
an
ermediate
step

The value of σ at the surface = $\sigma = \Delta\sigma + \sigma_o = 1.988$
From reference (c), this σ corresponds to a $\phi \approx 33°$
The remaining functions are:

$\tau = 1.24$
$\xi = 1.19$
$\eta = 1.55$

Hence $\Delta\xi = \xi - \xi_o = 1.16$
$\Delta\eta = \eta - \eta_o = 1.31$

p 7. Lay a straightedge from the τ scale at 1.24 to the point of intersection on the "Q" scale, step 2
p 8. Mark the point of intersection with the T scale, 6900 pounds
p 9. Lay a straightedge from the $\Delta\xi$ scale at 1.16 to the point of intersection on the "P" scale, step 4
p 10. Mark the point of intersection with the x scale, 325 feet
p 11. Lay a straightedge from the $\Delta\eta$ scale at 1.31 to the point of intersection on the "P" scale
p 12. Mark the point of intersection with the y scale, 365 feet



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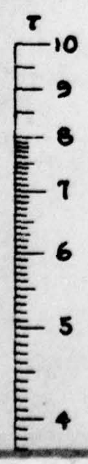
S = 500'

EP 12 Depth of T/B = 365'
EP 10 Trail Dist. to body, 325'



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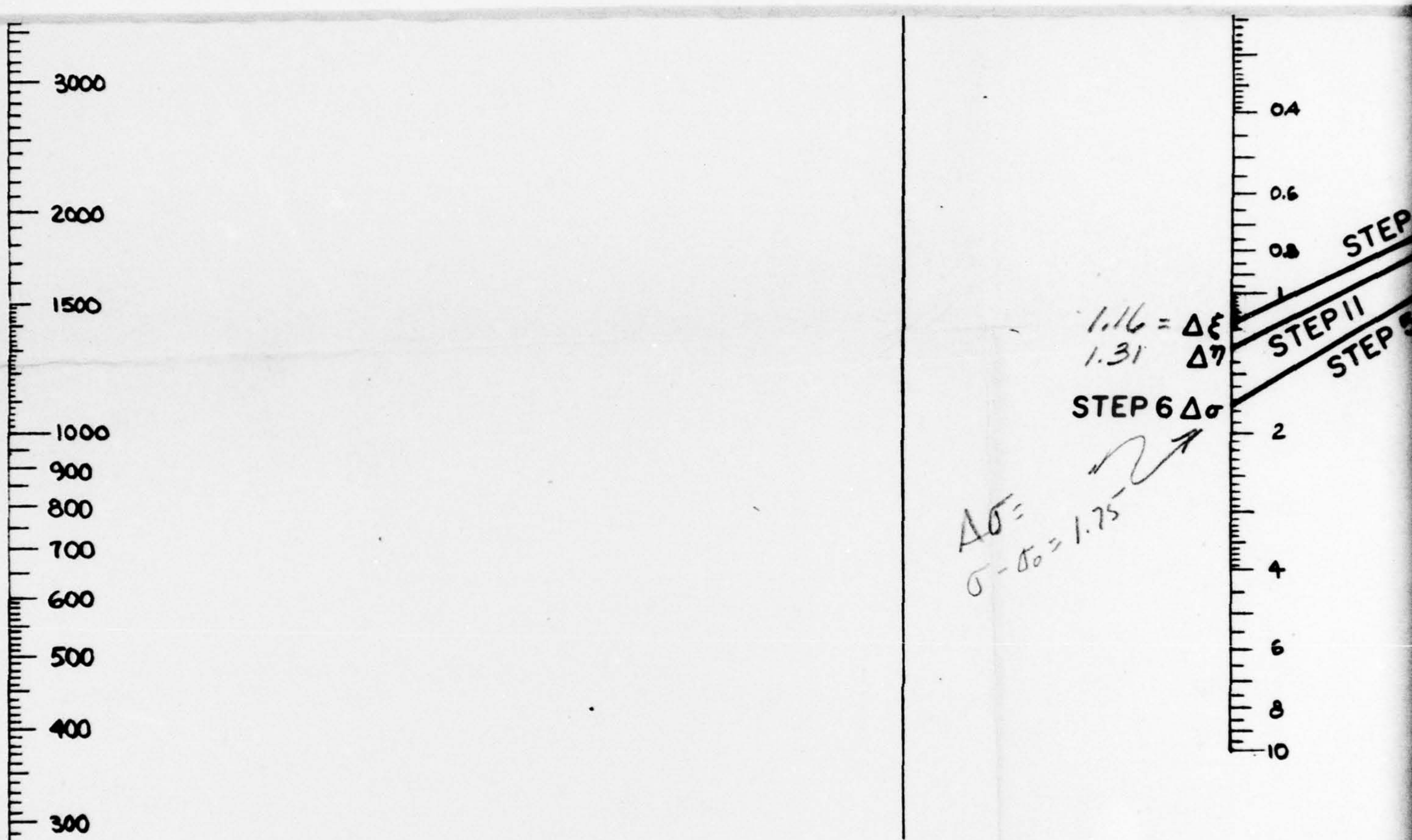


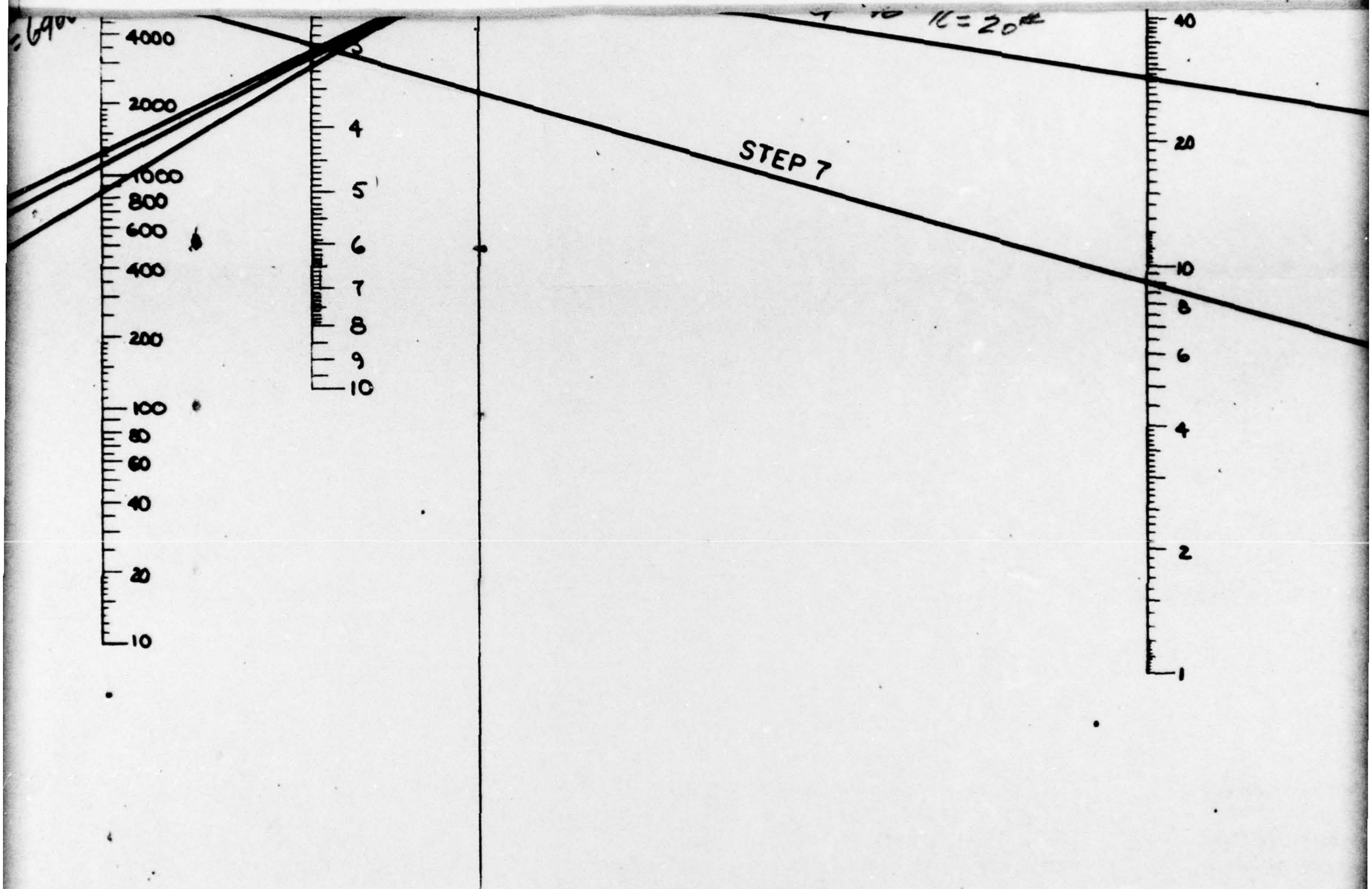
$\Delta\sigma = (\sigma - \sigma_0) = 1.75$

$1.75 = \sigma - 0.238$

$\sigma = 1.75 + 0.238$

$\sigma = 1.9888$

Fig. 1 - A N



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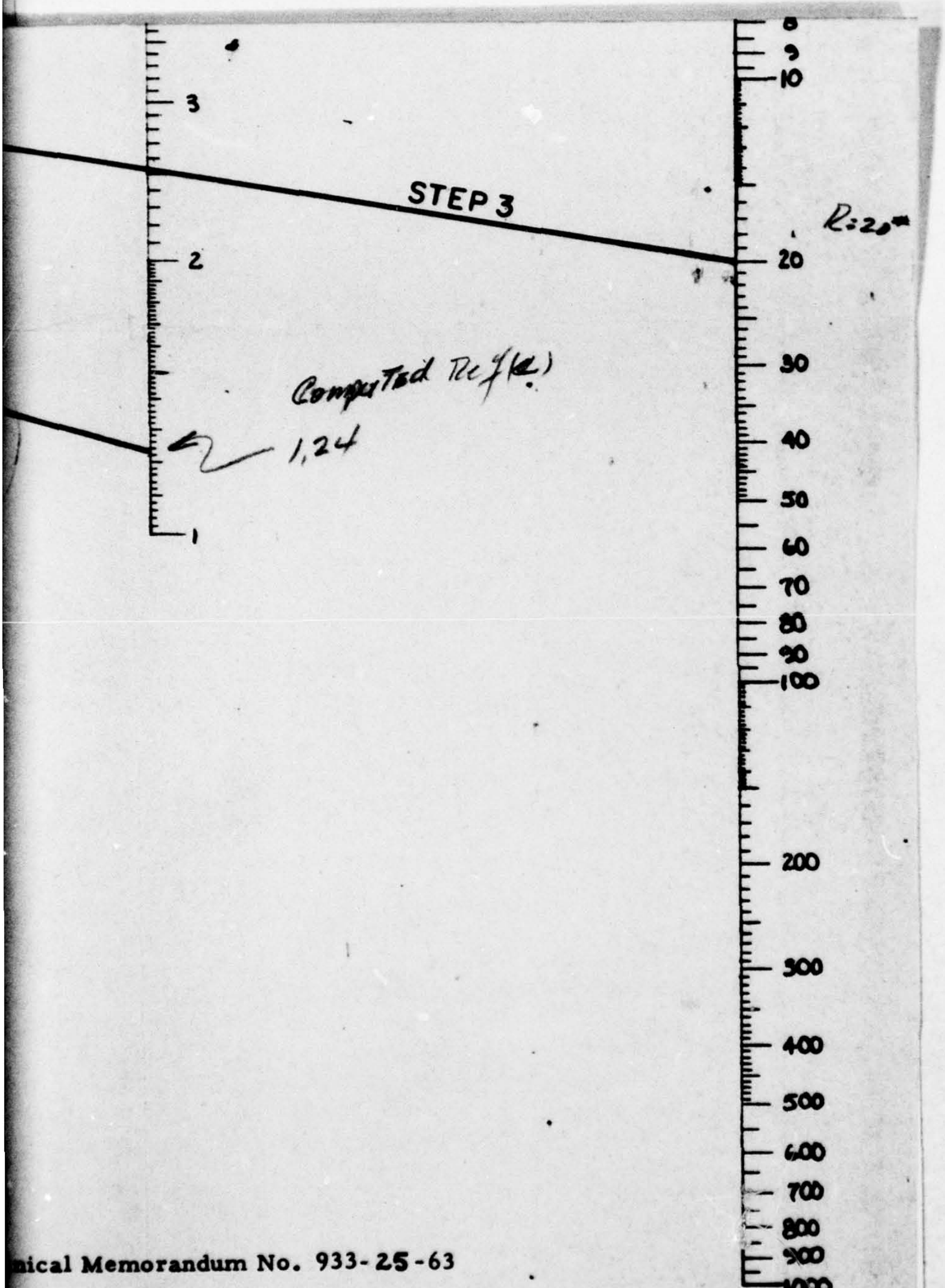
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STEP 3
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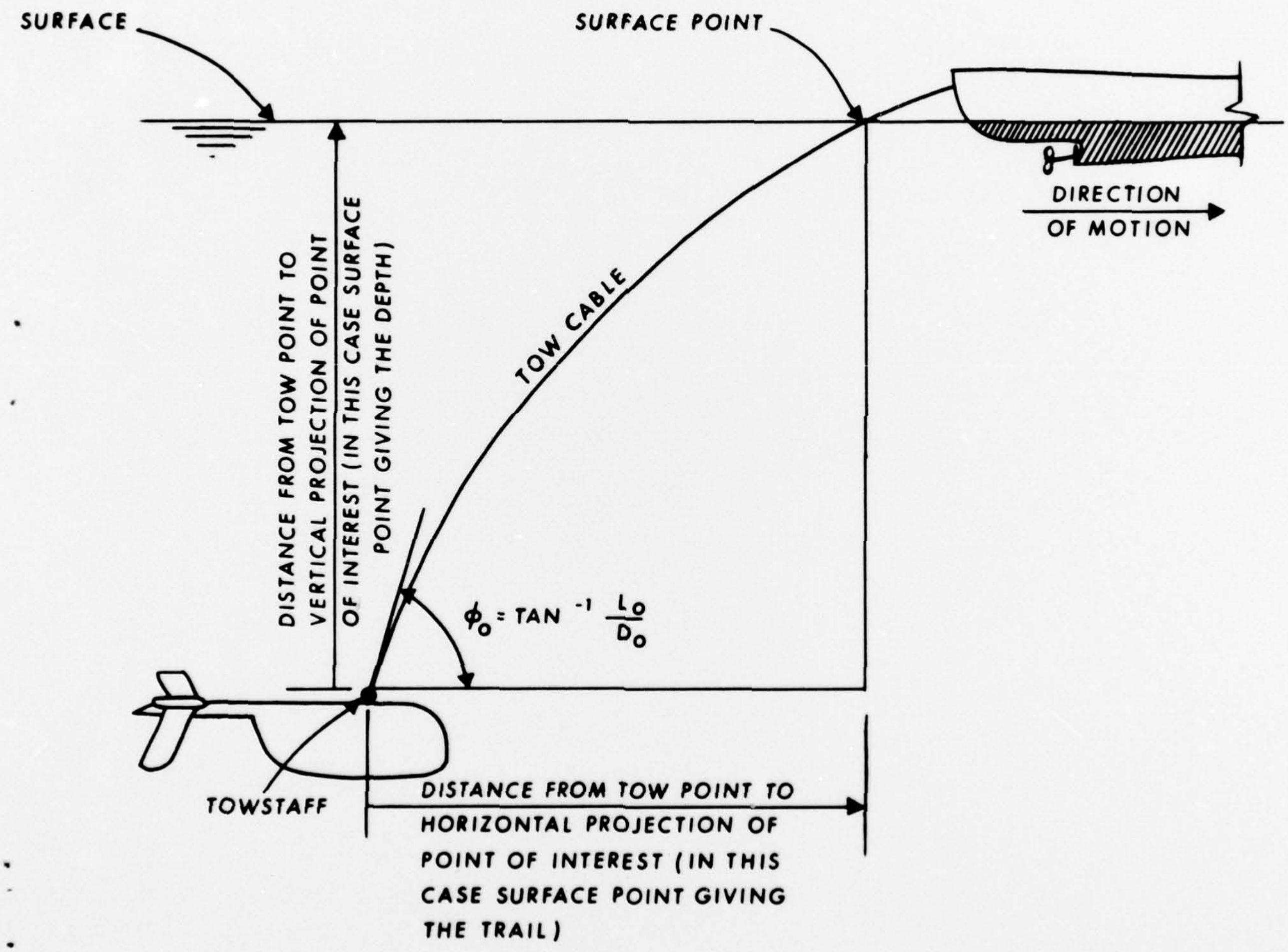

Fig. 2 - Geometric Orientation

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